Circuit for offset adjustment of input signals using precision DAC for measurement equipment

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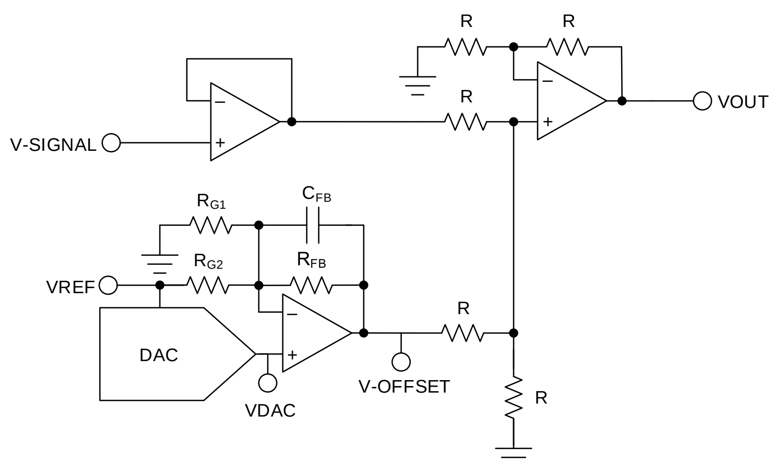
Design Goals

Power Supply	DAC Output	Voltage Output	Current Output
VCC: 24V, VSS: –5V, VDD: 5V	0V to 2.5V	0V to 5V	0A to 10A

Design Description

Signal-measurement equipment like Oscilloscope (DSO) and Data aquisition (DAQ) must manage input signals that are not within the input range of the measurement analog-to-digital converter (ADC). To bring the unknown input signal in the measurement range of the ADC, the first operation needed is offset control. A programmable offset control circuit providing both positive and negative offset, performs this function. This circuit uses a precision digital-to-analog converter (DAC), followed by a unipolar-to-bipolar conversion circuit using an op amp. The output of this circuit is fed to a summing amplifier that adds this DC output to the input signal.



Design Notes

1. Choose a DAC with the required resolution and output range
2. Choose an op amp with low offset and low drift to minimize error. Thermal noise may be an additional requirement in some applications
3. Choose R_{G1}, R_{G2}, and R_{FB} such that the desired output offset is met
4. Choose the compensation capacitor C_{FB} such that it is larger than the input capacitance of the op-amp inputs

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Design Steps

1. Select the DAC80504 device: a 16-bit, 4-channel buffered voltage output DAC with 2.5-V internal reference. Devices with an external reference option or devices with accessible internal references are desirable in this application as the reference is used to create an offset. The DAC selection in this design should primarily be based on DC error contributions, typically described by offset-error, gain-error, and integrated non-linearity (INL) error.
2. Select an op amp such as the OPA227 operational amplifier that combines low noise and wide bandwidth with high precision to make it the ideal choice for applications requiring both AC and precision DC performance. Amplifier input offset voltage (V_{OS}) is a key consideration for this design. V_{OS} of an operational amplifier is a typical data sheet specification, but in-circuit performance is also impacted by drift overtemperature, the common-mode rejection ratio (CMRR), and power supply rejection ratio (PSRR); therefore, give consideration to these parameters as well.
3. The DC transfer function of the offset voltage is given by:

$$V_{OFFSET} = V_{DAC}\left(1 + \frac{R_{FB}}{R_{G2}} + \frac{R_{FB}}{R_{G1}}\right) - V_{REF}\left(\frac{R_{FB}}{R_{G2}}\right)$$

   - First, using the previous transfer function, consider the negative full-scale output case when V_{DAC} is equal to 0V, V_{REF} is equal to 2.5V, and V_{OFFSET} is equal to –5V. This case is used to calculate the ratio of R_{FB} to R_{G2} and is shown in the following equation:

$$-5\,V = -\frac{R_{FB}}{R_{G2}}(2.5V)$$

     That gives, $R_{FB} = 2 \times R_{G2}$.
   - Second, consider the positive full-scale output case when V_{DAC} is equal to 2.5 V, V_{REF} is equal to 2.5V, and V_{OUT} is equal to 5V. This case is used to calculate the ratio of R_{FB} to R_{G1} and is shown in the following equation:

$$5V = \left(1 + \frac{R_{FB}}{R_{G2}} + \frac{R_{FB}}{R_{G1}}\right)(2.5\,V) - \left(\frac{R_{FB}}{R_{G2}}\right)(2.5\,V)$$

     This means, $R_{G1} = R_{FB}$.
   - Finally, select a value of R_{G2} to calculate the ideal values of R_{FB} and R_{G1}. The key considerations for seeding the value of R_{G2} should be the drive strength of the reference source as well as choosing small resistor values to minimize noise contributed by the resistor network. For this design, R_{G2} was chosen to be 8kΩ, which will limit the peak current draw from the reference source to approximately 312µA, under nominal conditions. The 312µA is well within the 5-mA limit of the DAC80504 device. By putting the value of R_{G2} in previous equations, R_{G1} and R_{FB} is calculated as $R_{G1} = R_{FB} = 16kΩ$.
4. In general, the compensation capacitor C_{FB} is not set by fixed equations, but rather by choosing values while observing the output small-signal step response. Through simulation in this example, select $C_{FB} \geq$ 22pF.

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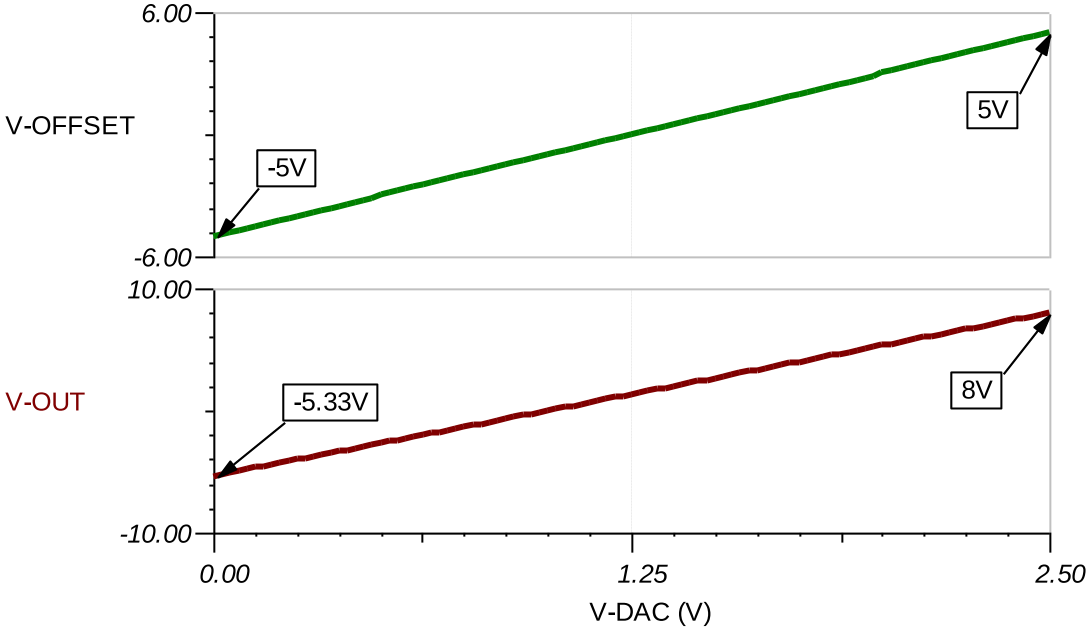
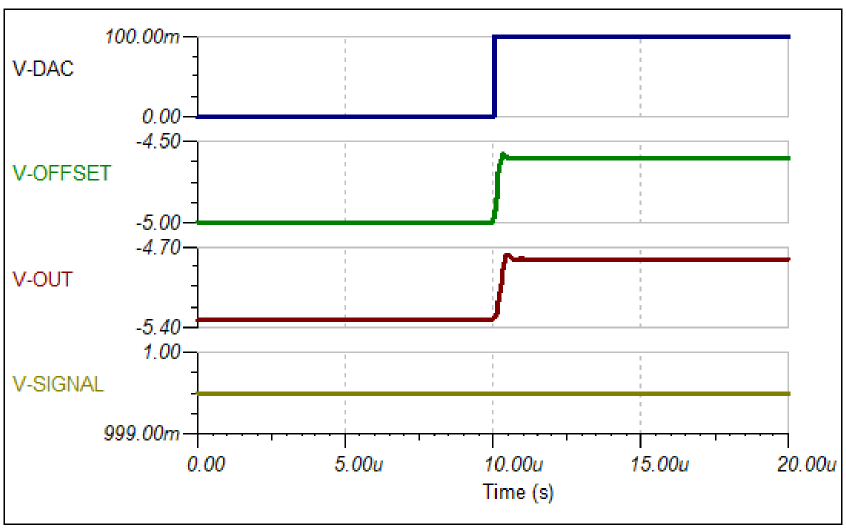
DC Transfer Characteristics



Small-Signal Step Response Without Compensation



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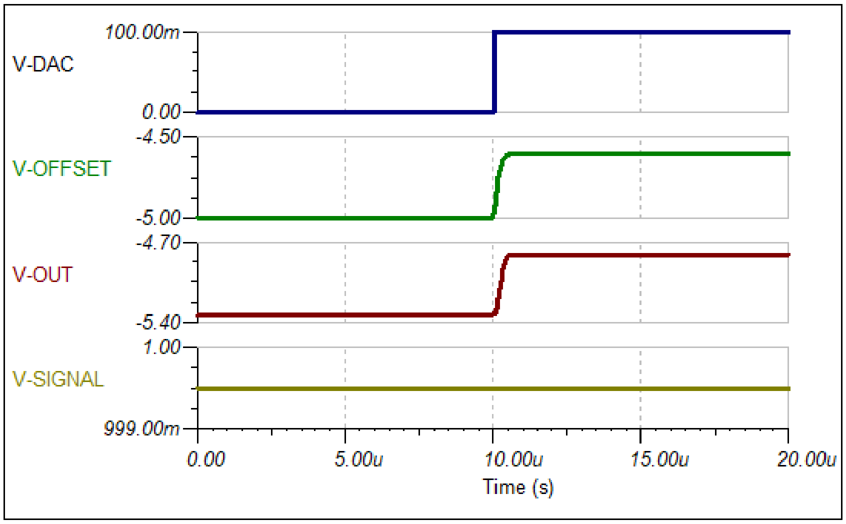
Small-Signal Step Response With C_{FB} = 22pF



Design Featured Devices and Alternative Parts

Device	Key Features	Link
DAC80504	4-channel, true 16-bit, SPI, voltage-output DAC with precision internal reference	http://www.ti.com/product/DAC80504
DAC80508	8-channel, true 16-bit, SPI, voltage-output DAC with precision internal reference	http://www.ti.com/product/DAC80508
DAC80004	Ultra-small, true 16-bit quad voltage output DAC with 1LSB INL/DNL	http://www.ti.com/product/DAC80004
DAC8560	16-bit, single-channel, low-power, ultra-low glitch, voltage output DAC with 2.5V, 2ppm/°C reference	http://www.ti.com/product/DAC8560
OPA227	High precision, low noise operational amplifiers	http://www.ti.com/product/OPA227
OPA188	Precision, low-noise, rail-to-rail output, 36-V zero-drift operational amplifier	http://www.ti.com/product/OPA188

Design References

See *Analog Engineer's Circuit Cookbooks* for TI's comprehensive circuit library.

Link to Key Files

TINA source files – http://www.ti.com/lit/zip/sbam418.

For direct support from TI Engineers use the E2E community:

e2e.ti.com

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